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THE EXUDATION OF ICE FROM STEMS OF PLANTS

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I. Introduction

NOCTURNAL radiation is generally a passing of radiant energy from terrestrial substances into space. On a clear night the rate at which radiation passes outward from a lamp-black surface is very great, amounting to about one tenth of the solar constant. Of course, not all substances lose heat at this rate. This loss of heat by radiation produces peculiar formations of ice, some of which will now be mentioned.

Ground Ice or Columnar Ice.—The most familiar freak of ice formation occurs on bare, clayey soils which contain a certain minimum amount of moisture. If the moisture content of the soil falls below the minimum value (which no doubt varies for different soils) then evaporation occurs as rapidly as the moisture is brought to the surface (by capillary action) and no ice is formed. According to the writer's observations the ice is formed in contact with a nucleus which may be a grain of sand, a small pebble, etc. The earthy material has a higher emissivity than the water, it cools the more rapidly, and the water is frozen to the under side of the nucleus. As heat is lost, more ice is formed and, as it accumulates, rises in columns, as it is to be observed everywhere on cold mornings. The water is supplied by capillary movement in the soil, from the surface of which the ground ice may be readily lifted, since in freezing weather the ice is not frozen into the soil.[1] The general experience is to find the ground ice supporting a nucleus (say a grain of sand, or even large stones, 3 × 1½ × 1 inches in size). The nuclei may be thinly distributed. The writer has observed several large areas, 3 × 1½ feet which did not contain nuclei, from which it appears that this type of ice formation can occur without having a nucleus (gravel, etc.) to start the refrigeration.

Anchor Ice.—Barnes[2] has made a prolonged study of the formation of anchor ice at the bottom of the St. Lawrence river. This kind of ice consists of fine spicules which adhere to the bottom of the river. It is a friable mass which may vary from six to eight feet in thickness. According to Barnes this ice is formed as a result of the greater emissivity, and hence the greater cooling of the material composing the river bottom.

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[1] Abbe, *Amer. Meteorological Jour.*, 9, p. 523, 1893.

[2] "Ice Formation with Special Reference to Anchor Ice and Frazil," H. T. Barnes, *Monthly Weather Review*, May, 1907, p. 225.

Hoar Frost.—This is another example of ice formation as the result of cooling by radiation. Here, however, the accepted explanation is that the ice spicules are formed by accretion, as the result of the deposition of moisture from the surrounding air.

The foregoing are familiar and interesting illustrations of ice formations on substances as the result primarily of the loss of heat by radiation. We have now to consider a rarer phenomenon, which is the subject of the present paper.

Ice Formations on Plants.—According to the writer's observations the amount of ice formed upon a plant stem is a function of (1) the rate at which water can rise by capillary action in the sap tubes within the stem, (2) the ease with which the moisture can pass out to the surface, (3) the rate of evaporation from the surface (convection, wind-velocity) and (4) the emissivity of the surface of the stem. Instead of the title "Exudation of Ice," a more pretentious title would have been "*The Capillary Movement of Water—An Experimental Demonstration by Means of the Formation of Ice Fringes on Plants.*" This might appear more scientific and one could discuss the capillary movement of water as a function of the temperature of the stem; the size of bore and number of (sap) tubes; the thickness and permeability of the walls of these tubes, etc. However, the present communication makes no pretense at such completeness of the investigation. In fact, the subject of ice formation forced itself upon the writer at a time when other duties were pressing, and hence it could not be given the attention it deserved. As a result, the experimental tests were usually carried out only to the extent of refuting the various notions held by various persons as to the cause of this ice formation. It was shown that the formation of fringes of ice on plant stems is not the result of accretion, hydrostatic pressure, rifts in the stem, moisture in the bark, the presence of sap, etc., but that it is the result primarily of the capillary movement of water in the numerous sap tubes which are to be found in those plant stems, upon which the ice formations are the most conspicuous.

II. HISTORICAL DATA

One of the earliest descriptions of the exudation of ice fringes from plants was published by Herschel,[3] about eighty years ago. His observations relate to the icy fringes which were formed around thistle stalks, and stumps of heliotropes many specimens of which were still green. Stephen Elliot[4] had previously described a remarkable protrusion of fibers of ice from the stems of flea bane (*Conyza bifrons*).

[3] Sir John Herschel, *Phil. Mag.* (3), 2, p. 110, 1833.

[4] Stephen Elliot, "Sketch of the Botany of South Carolina and Georgia," published in 1824; Vol. 2, p. 322. Quoted by Le Conte.

The fullest account, with an attempted explanation of this phenomenon, was given by John Le Conte[5] about sixty-three years ago. His observations are on two species of flea bane, *Pluchea bifrons,* and *Pluchea camphorata,* which he found growing in wet soils, around ponds and along roadside ditches in the lowlands of South Carolina and Georgia. In these plants the root is perennial, but the stem is annual and herbaceous.

Le Conte's descriptions differ materially from my own. His observations appeared to establish the following facts in relation to the phenomenon.

> 1. The depositions of ice are entirely confined to the immediate neighborhood of the roots of the plants, the upper parts of the tall unbroken stalks being quite free from them. They frequently commence two or three inches from the ground, and extend from three to four inches along the axis of the stem. The stalks are dead, and quite dry to within about six inches of the earth, below which they are generally green and succulent. The plant has a large and porous pith, which is always saturated with moisture, as high as six or seven inches from the base of the stem. From this it would appear that the ice was formed on the green stems, as was true of many of the specimens of heliotrope described by Herschel.
>
> 2. The ice emanates in a kind of riband, or frill-shaped, wavy, friable, semipellucid excrescence,

the structure of which (quoting Herschel) "is fibrous like that of the fibrous variety of gypsum, presenting a glassy silky wavy surface; the direction of the fibers being at right angles to the stem or horizontal." Le Conte found that the number of ribands varied from one to five, which issued from the stems in vertical or longitudinal lines, often unsymmetrically displaced around the axis. He frequently observed the icy excrescences to exceed five inches in length; often curled back so that the remote extremity of the frill came close to the line of attachment to the stalk.

From this it may be noticed that the amount of ice formed is very considerable. Evidently the moisture must come from within the plant. The amount of water congealed during a single night is vastly too great to come from the aqueous vapor in the atmosphere, hence the phenomenon can not be a modification of hoar-frost. In fact, in the illustrations to be cited presently, which were observed by the writer, the excrescences of ice on one particular species of plant were formed every night which was sufficiently cool for ice formation, although there was little or no formation of hoar frost anywhere in the vicinity.

3. Although the ice sheets appeared to protrude from the interior of the stem, both Herschel and Le Conte found that usually the stems were solid and that the ice terminated at the surface.

> The point of attachment of the ice was always the wood, beneath the outer bark or epidermis, which the frozen sheets had in every instance stripped off, and forced out to a distance.

[5] John Le Conte, *Proc. Amer. Assoc. Adv. Sci.*, Vol. 3, p. 20, 1850.

When the frost was severe, Le Conte found that the ice riband was continuous with the frozen pith, through a longitudinal rift in the woody stem.

4. Le Conte found that

> the phenomenon took place in the same plant during several consecutive nights; and when the wood was not rifted, frequently from the same portion of the stalk. When the wood was split, however, the deposition of ice occurred lower down the stem, at a part which was unaffected by the frost of the previous night. The stalks thus became completely rifted by a succession of severe nights, from the height of six or seven inches down to the ground. This is unquestionably one of the reasons why these exudations of ice are seldom observed after the middle of the winter, for the stalks are usually destroyed before this period.

Ward[6] has given a rather popular description of the occurrence of ice fringes. He describes the fringes as projecting out horizontally, "not straight and stiff, but gently and gracefully curving or coiling into a beautiful conch-like roll at the distal end." His observations were probably of short duration, otherwise he would have found but few instances in which the "fringes are attached at regular intervals around the stem, like paddles of a turbine wheel." He found that the bark was split into strips at the zone occupied by the ice-sheets. He concluded that the ice had passed through these rifts in the bark. He thought that the water might have been pressed or drawn up through the cambium layer. He wisely dismisses the explanation because it "explained too much, since no reason can be assigned why the phenomenon should not be universal and not confined to one species."[7] In the present paper the micro-photographs of the cross-sections of various plants will assign this reason, viz., the difference in the porosity of the stems.

Le Conte considered the ice formation on plants to be a physical phenomenon, having no connection with the vitality of the stem. His explanation of the formation was that the moisture from the pith passes out along the wedge-shaped medullary rays, which are to be found in abundance in this plant, and is frozen on the outside of the stem. He considered that the wedge-shaped medullary rays exerted a "projectile force" which brings the moisture to the surface. The exudation of ice columns from the earth he referred to the same cause, viz., a rapid and forcible expansion along capillary tubes.

To the writer it does not appear necessary to postulate a complex "projectile force" to explain the ice fringes on plants. In fact, the plants upon which ice is formed in the great abundance have a preponderance of sap tubes, only an insignificant part of the stem being occupied by medullary rays.

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[6] Ward, *Botanical Gazette*, 18, p. 183, 1893, ''Frost Freaks of the Dittany.''

[7] Ward quotes Gray's Manual, 1848, in which *Helianthemum canadense* is described as behaving in a similar way.

III. RECENT DATA

The present observations are on *Cunila mariana,* or Dittany, the stem of which is a herbaceous annual with perennial roots. This plant seems to thrive on dry ground, even on bare hillsides exposed to the blazing sun, where there is nothing but gravel and a few "asters." Other samples were found under trees where either the shade or the gravelly character of the soil prevented a luxuriant growth of other plants. The finest samples were found on a hillside which contained plenty of moisture, which was free from trees, but contained shrubbery.

The first observations were made on a frosty morning in November, 1913. The first example, because of its white ribbony character, was passed by, thinking it was something thrown from a passing carriage. The conspicuous fibrous white loops and ribbons drew my attention, and it was at once observed that they occurred upon only one species of herbaceous plant.

Owing to the pressure of other problems requiring close attention, the tendency at the very first was to dismiss the subject by accepting Le Conte's explanation that the moisture comes from the pith. This explanation was at once disproved, however, by the observations on the splinters of the *Cunila* stem, which formed ice always on the outside of the stem, but never on the pith. This, of course, should be expected, for pith is composed of small hexahedral cells along which water can not pass by capillary attraction, and it would be very unlikely that it would be transferred by soaking through the cell walls.

It was concluded that the moisture for producing the ice fringe came from the sap tubes and experiments were devised to prove this assumption. Photographs were taken of thin sections across the stems of heliotrope, thistle and also of an aster which was found near a *Cunila* stalk. The object in giving these photo-micrographs (which were very kindly prepared by Mr. E. D. Tillyer) is to show typical examples which have but few sap tubes and which form but little or no ice; also typical examples of plants which have numerous sap tubes and which form an abundance of ice fringes.

The aster is typical of plants having but few sap tubes. As shown in Fig. 1, the woody structure is very compact, with but few sap tubes. All these photo-microsections are magnified fifty times, from which one can obtain some idea of the great difference in porosity of the different plants.

On only one occasion was ice observed upon the stem of the aster. The ice was a small "tooth" formed close to the ground. From the section shown in Fig. 1 it is evident that the structure of the wood fiber is so close that the moisture which is drawn up within the stem by capillary attraction can reach the surface of the stem at only a very slow rate. Hence the moisture disappears by evaporation as rapidly as it comes to the surface. The thistle (Fig. 2) and the heliotrope

(Fig. 3) stems have numerous large sap tubes. In the thistle stem there is a row of large tubes situated near the bark. The presence of these large tubes filled with sap may explain the formation of ice fringes, as observed by Herschel.

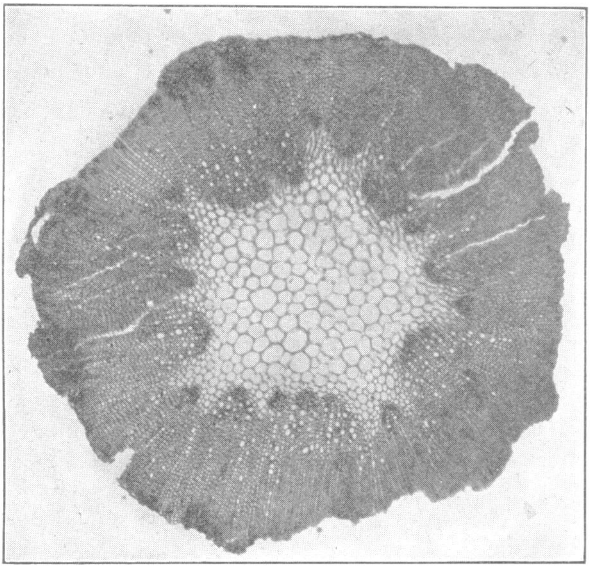

Fig. 1. Photomicrograph of a Cross Section of the Stem of an Aster. It is typical of plants having but few sap tubes, and forming no ice fringes.

A photo-micrograph of a thin section of *Cunila* is shown in Fig. 4. The numerous holes in the wood are the "sap tubes," which form an easy path for the moisture to rise within the stem, by capillary attrac-

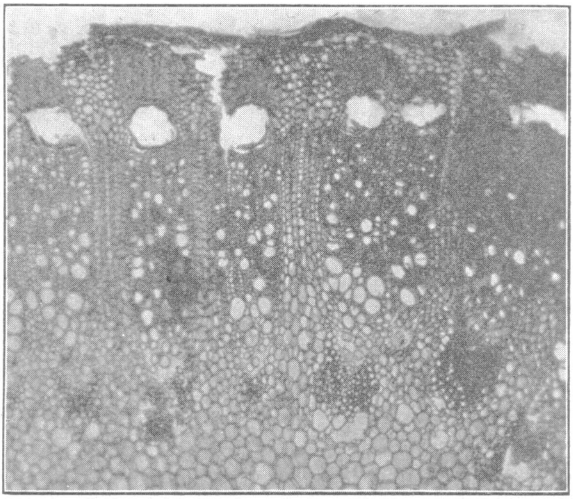

Fig. 2. Photomicrograph of a Section of the Stem of a Thistle, showing numerous sap tubes.

tion. It would be interesting to determine to what extent this capillary movement of water is affected by the temperature of the surroundings.

The explanation of the formation of ice fringes, which are found to occur so abundantly upon the stems of the *Cunila,* and which are not found upon other plants, is based upon the presence of a great number of closely adjoining sap tubes within the stem of the *Cunila.* But even the very woody portion of the base of the *Cunila* stem was found to be inactive in the formation of ice fringes.

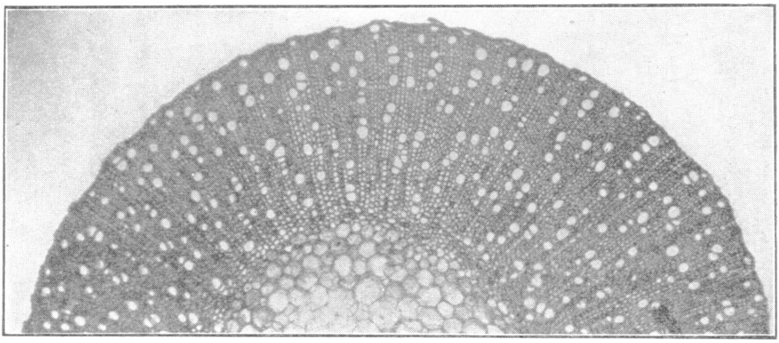

FIG. 3. PHOTOMICROGRAPH OF A CROSS SECTION OF THE STEM OF HELIOTROPE, showing numerous but widely separated sap tubes.

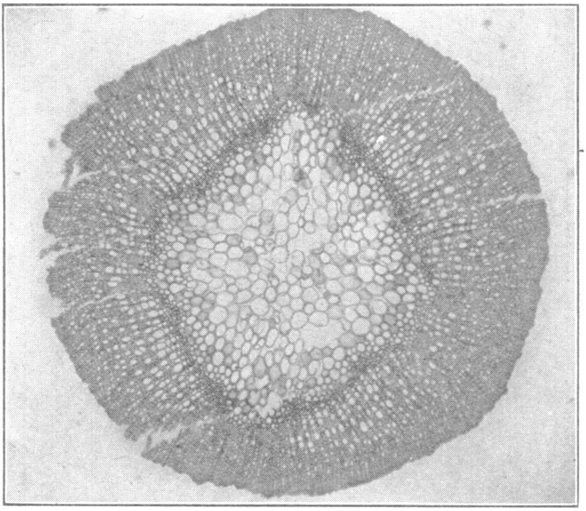

FIG. 4. PHOTOMICROGRAPH OF A CROSS SECTION OF THE STEM OF *Cunila mariana.* It is typical of plants having an abundance of sap tubes which transfer moisture to the surface by capillary attraction of the water in the soil.

It was found that the ice fringes rarely start from the side of the stem where the pith is closest to the bark. This eliminates to some extent the question whether the pith is instrumental in forming the ice fringes. In the splinters (and in the rifted stems) of *Cunila* at no time was ice found to have formed along the line of separation of the stem. This seemed puzzling at first, for it appeared to contradict the idea that the moisture comes from the sap tubes within the stem; in which case one would expect to find the formation of ice fringes facilitated upon the surface laid bare by splitting. The microsections of the *Cunila* stems show in a very unexpected manner why no ice-fringes are formed upon the rifted surface of the stem. As already stated, the rift always occurs at the "corners" of the pith where the woody part of the stem is the thinnest. In Fig. 4 it may be noticed that at these four points, where the wood is the thinnest, there are but few, if any, sap tubes. Hence one need not expect, as a rule, to find ice formations upon the surfaces formed by splitting.

IV. OBSERVATIONS SHOWING HOW THE ICE FRINGE GROWS

One of the most interesting observations was on the formation of the ice fringe from its very beginning. This was witnessed by several of my colleagues who were called in to verify the observations. On a cold morning, February 16, 1913, several stems, placed in water, were exposed outside the laboratory window, and in about 20 minutes the ice fringe was observed to be forming. It consisted of a row of fine hairs extending up and down over a length of about 4 mm. of the stem, and projecting out horizontally 0.2 to 0.3 mm., as shown in Fig 5, *a*. These filaments were visible only when viewed against sky light, and they melted immediately on lifting the glass cover. The fringe did not appear to form at the line where the pith is closest to the surface of the stem. The experiment was repeated again during the evening. Within half an hour after placing the samples in the cold air one stem showed several fringes in the form of thin transparent "teeth," each one being about 12 mm. in length and about 1 mm. in height. Another stem showed a fine hairy fringe which was visible when viewed against a gaslight. Within half an hour this hairy fringe appeared to be solid with some of the fine hairs extending horizontally outward through the solid "tooth" of ice, as shown in Fig. 5, *b*. This, of course, is the general structure of the fringes. By the next morning numerous wide fringes had formed on these stems. In another sample, the tooth of ice pushed out a narrow strip of bark. In these tests the receptacle containing the water was small, and hence the whole cooled very rapidly and the water froze, which prevented the growth of the ice fringes. It is to be noticed that the ice fringe forms some distance up the stem at a point where it cools the quickest and where the moisture has risen to about its maximum height. The experiment was repeated ("Test *C*," which was started February 17, contained half a dozen samples of *Cunila* and a stem of an "aster") using a large test tube. The test tube was imbedded in wool to retard cooling and freezing. Within 15 minutes after placing this test outside of the laboratory window two small fringes, 1.5 mm. long and about 0.3 mm. high, were noticed when viewed against sky light. This test was prolonged for some days and nights and a photograph was taken (February 18, 1913) (Fig. 6) showing that the stems in water form ice just as they do when attached to the roots. In this photograph, which is magnified slightly (1.2) about one third of the upper part of the largest fringe is broken off. These fringes appear to be a little more transparent than those found in the field, owing to the fact that they had begun to melt while taking the photograph. No ice or moisture was formed upon the aster stem, which is in agreement with the field observations.

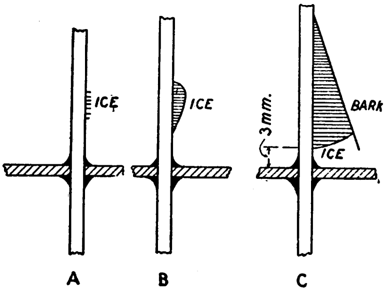

FIG. 5. ILLUSTRATING SUCCESSIVE STAGES IN THE GROWTH OF THE ICE FRINGE on the stem of *Cunila mariana* when placed in water and exposed to a freezing atmosphere.

As may be seen from Fig. 4, the *Cunila* stem on drying (shrinking) splits easily into four parts, owing to the small amount of wood fiber at the four "sides" of the stem. One of the samples used in "Test *C*" was a splinter, consisting of one quarter of the stem, about 6 cm. in length, with a line of pith adhering to the inner side. On the following morning, and on subsequent days, this splinter showed a fringe of ice on the woody surface, but at no time was there ice formed on the pith. An interesting feature (which to the writer became a common observation) was that the ice fringe did not always start at the "corner" of the stem where the wood is thinnest, but at a mid-point (see Fig. 4). From the photo-micrograph of a thin section of the stem (Fig. 4) it appears that the largest part of the ice fringe may form at the point where the sap tubes lie nearest the surface, hence where the moisture can be supplied the most easily.

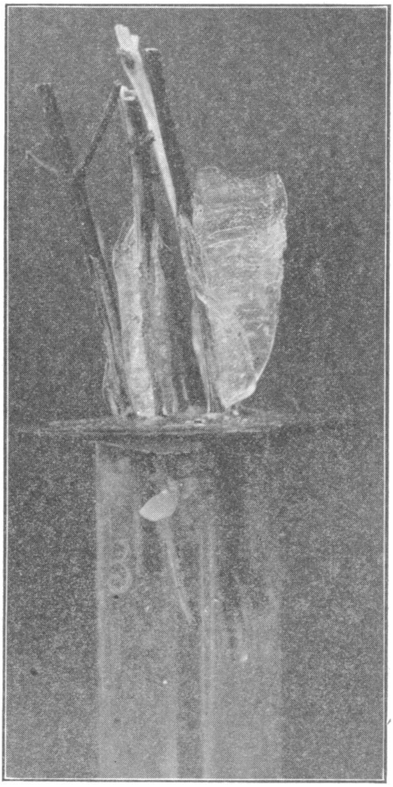

FIG. 6. SHOWING ICE FRINGES FROZEN UPON STEMS OF *Cunila mariana* which were in a test tube containing water.

The ease with which these stems became saturated with water after having been drying for weeks is another item worth noticing. All the stems used in "Tests *C* and *D*" (Fig. 6 is Test *C*) had been in the laboratory for some time. Some of them had been gathered in November, 1913, and had been freed of bark by previous ice formations.

It is generally supposed that the ice is formed more easily in the fall (when the plants are fresh) than in the late winter. This seems to be true to some extent according to my field observations and to my laboratory tests. In the latter the ice did not seem to form so abundantly after the stems had soaked for some weeks. It seemed as though the sap tubes became clogged or the plant had begun to decay.

V. Description of Photographs of Ice Fringes

The attempts at photographing the ice fringes as they occurred in the woods were far from satisfactory. This was owing to the fact that at 8 A.M. the illumination was low. A wide stop was used in the camera and consequently the objects are in focus only in the center of the photograph. They serve the purpose, however, to illustrate their general appearance as found in the woods. The ice fringes are generally viewed at an angle at about 45° with the ground.

The photographs in Fig. 7 were obtained in January, 1915. They are typical of what one finds as regards size and general appearance of the ice fringes. The fringe in the lower right-hand corner is composed of three whorls. The open space in the fringe is shown by the round dark spot in the center. The photographs shown in Fig. 8 were obtained in the middle of January, 1915. The ice formation on the stalk in the lower left-hand corner of the photograph contains two beautifully folded fringes, the markings of which are unfortunately lost in the print.

The finest photographs were obtained by collecting a number of ice fringes one cold frosty morning (January 6, 1914) and having them photographed at the Bureau of Standards. Grateful acknowledgment is due Mr. E. D. Tillyer for his painstaking care in making these photographs, which no doubt are the finest records yet obtained of these beautiful ice formations.

In Fig. 9 the four most conspicuous ice fringes are lettered *a, b, c, d,* which makes identification easy in Figs. 10 and 11. In these illustrations the ice fringes were photographed from different sides. In Fig. 9, *a,* it may be noticed that the stem is free from bark. In Figs. 9 and 10 an extremely thin delicate fringe may be noticed protruding from what appears to be a rift in the stem, but what in reality is a piece of bark. It is an excellent illustration of the second stage in the formation of the ice fringe, as described on a preceding page and illustrated in Fig. 5, *b*. In Fig. 10 the oft-mentioned, thin, wedge-shaped fringe (see Fig. 9) is shown to advantage, protruding (upwards in the photograph) from above the large fringes. The *Cunila* stalk (Figs. 10 and 11) shown in these plates is typical of what one finds after several ice formations, when the stem is well stripped of bark. The stem is 2.2 mm. in diameter and it is not rifted. As shown in Fig. 10, the "width" of the fringe adhering to the stem is 3 cm. It extends out horizontally 3 cm. from the stem. The distance from the stem to the extreme distal end of the loop is 4 cm. The weight of the ice formation is over 5 grams.

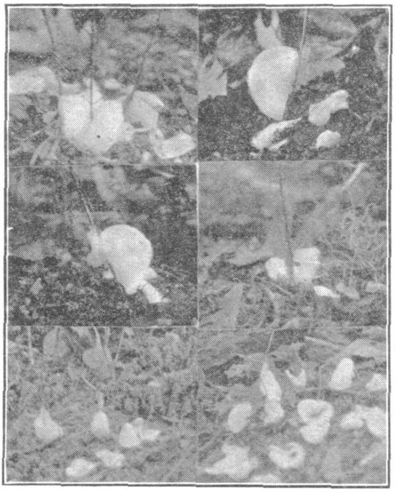

FIG. 7. A COLLECTION OF 6 PHOTOGRAPHS SHOWING VARIOUS FORMATIONS OF ICE FRINGES ON *Cunila*.

Fig. 9, *b*, consists of three splinters, united at the base of the stem. They are, of course, the remnants of the stalk which had long since disappeared. The dark line in the wood is the pith, which is shown to better advantage in Fig. 11. In Figs. 9, *d*, and 11, *b*, the pith-side of the splinters is shown to advantage. We thus have a photographic record of the ice formation, not only upon the unrifted stalk, Fig. 9, *a*, but also of the formation on the rifted stalk, Fig. 9, *c*, and of the formation upon the bare splinters, Fig. 9, *b* and *d*. The fringe in Fig. 9, *b*, is an unusually interesting ice formation. The peculiar whorl in the center is the meeting point of two fringes (see Fig. 12) both of which began curving clockwise. The extreme thinness and the great transparency is to be noticed by the light and the dark streaks through the fringes in Fig. 9, *d*.

The small ice fringes on the stalk shown in Figs. 9, *c*, and 11, *c*, are of interest because they occur upon a thin stem which is split into two parts, the rift being easily distinguished in the photographs. In fact, most of the rift is above the ice fringes. This ice formation is also conspicuous in having pushed out some of the bark as illustrated in Fig. 5, *c*. This is an excel-

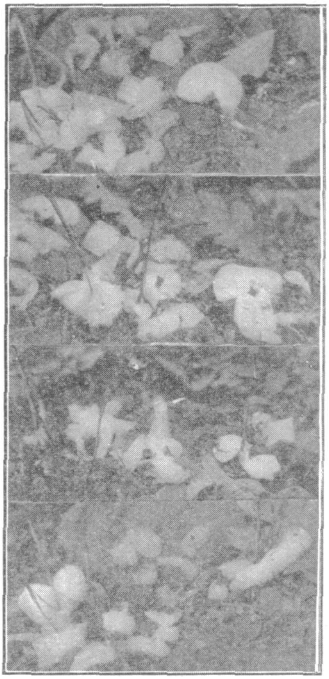

FIG. 8. SHOWING A COLLECTION OF FOUR PHOTOGRAPHS OF ICE FRINGES ON *Cunila*.

lent photographic record showing that the ice is not formed upon the pith (Fig. 9, *b*) or in the rift of the *Cunila* stem.

Figs. 9, *d* and 11, *d*, give a further illustration of the formation of ice fringes upon fragments of stems of the *Cunila*. The sample is a very small one. The stump of the stalk had to be cut out of the ground in order to obtain the fringes. Some of the ground is still adhering to the stem. One of the fringes is broken off. The extremely thin translucent fringe (it appears to be dark, owing to the dark background) on the right-hand side of Fig. 9, *d*, is an excellent photographic record of the manner of growth of the ice fringe—as described on a previous

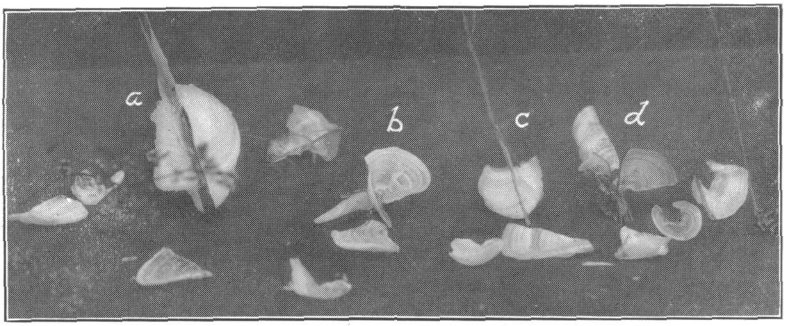

FIG. 9. PHOTOGRAPHS OF ICE FRINGES ON *Cunila mariana*.

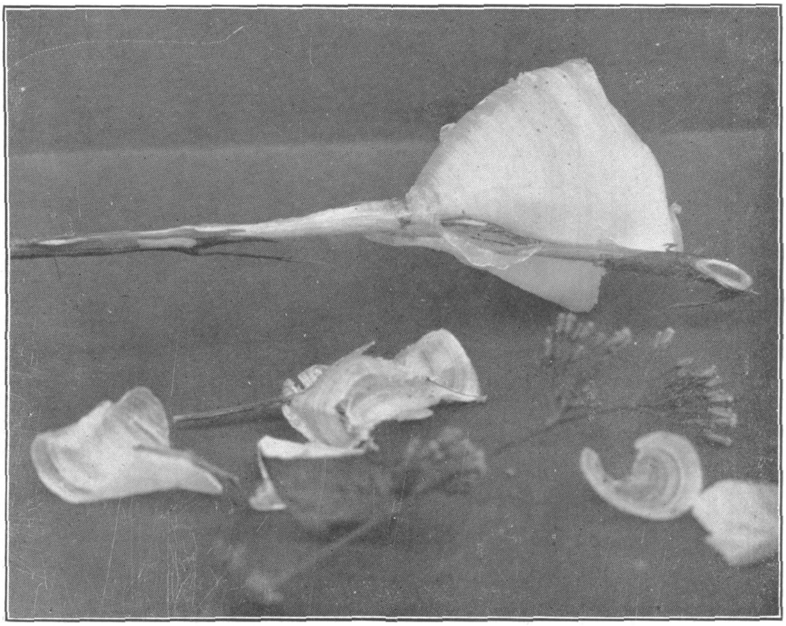

FIG. 10. ENLARGED VIEW OF ICE FRINGES ON *Cunila*.

page. The growth of the fringe is along a straight edge which appears almost horizontal in the photograph. This, however, is partly owing to the peculiar curvature of the fringe. The distal edge is straight and smooth, just as it started when near the stem. The photographic record is therefore an excellent contradiction of the hoar-frost theory of accumulation in which the ice is formed in spicules. The dark streak along the fragment of stem is pith. The ice fringe is upon the woody side of the stem. In Fig. 12 is given a diagrammatic illustration of the whorled fringe shown in Figs. 9 and 11, *b*. All the plates show

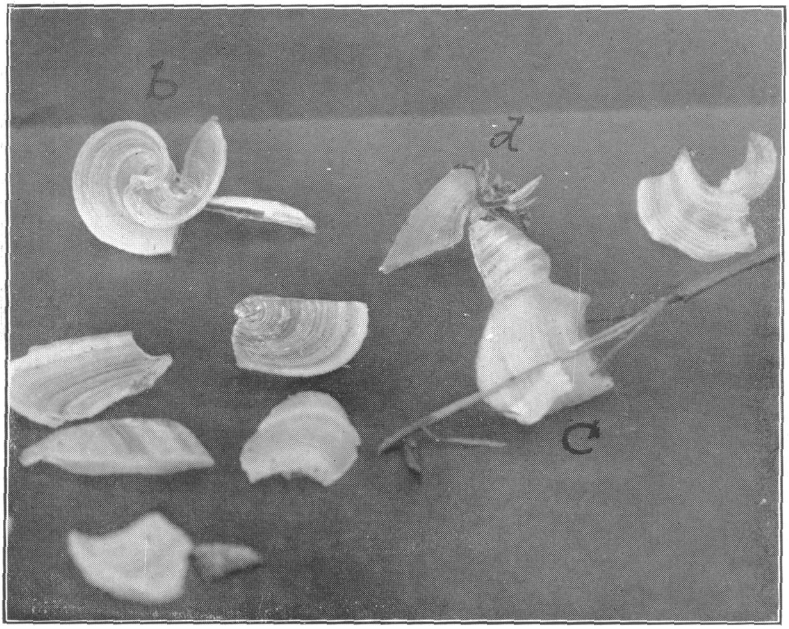

FIG. 11. ENLARGED VIEW OF ICE FRINGES ON *Cunila*.

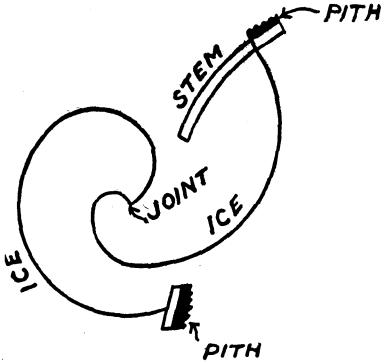

FIG. 12. ILLUSTRATING THE PECULIAR GROWTH OF THE ICE FRINGE SHOWN IN FIGS. 9 AND 11*b*.

fragments of ice fringes, the bright and dark streaks of which are owing to the difference in thickness and transparency of the ice. Fig. 6 mentioned elsewhere is a photographic record of the laboratory. It was

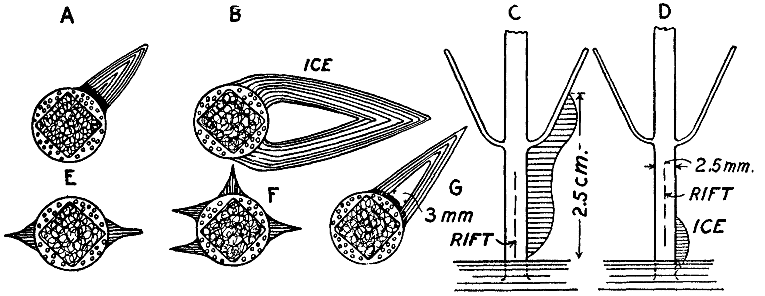

FIG. 13. ILLUSTRATING THE BEGINNING OF THE ICE-FORMATION AS OBSERVED IN THE FIELD AND IN THE LABORATORY.

taken by the writer Feb. 18, 1914. The test-tube was about 20 mm. in diameter, which gives one some idea of the dimensions. The test is described on a preceding page. This record is of interest mainly in showing that the *Cunila* stems after having been in the laboratory for some months form ice fringes just as they do when attached to the roots. In Figs. 13 and 14 are given illustrations of the growth of ice fringes

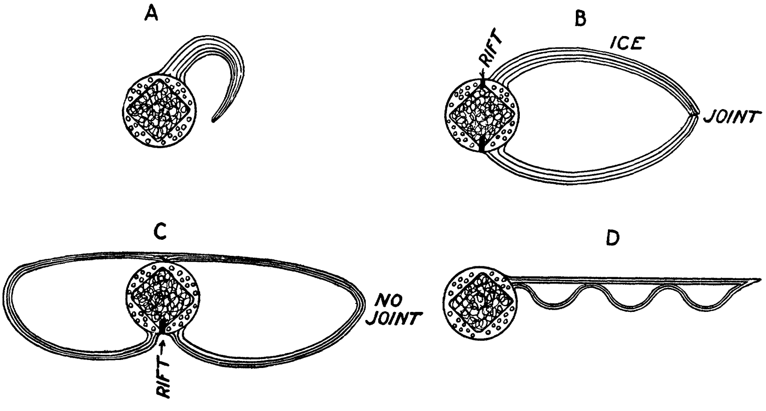

FIG. 14. ILLUSTRATING LATER STAGES IN THE FORMATION OF ICE FRINGES AS OBSERVED IN THE FIELD.

as observed in the field and in the laboratory. They are self-explanatory, and while it is true that they are diagrammatic, they nevertheless illustrate the complex and diversified manner in which the fringes occur. It seems needless to say that they are reproduced from sketches made at the time of observation.

VI. SUMMARY.

This paper deals with the formation of ice fringes upon the Dittany, *Cunila mariana.* The data presented are based upon experiments and observations, in the field and in the laboratory.

It was observed that the ice fringes are formed when the temperature falls to freezing (0° C., 32° F.); but they are not a function of the hoar-frost which may be present upon the ground.

The ice fringes do not form upon the side of a splinter which contains the pith or upon the line of fracture, but upon the outer woody surface. The formation of the ice fringe, however, is not a function of the surface condition of the stem. The stem is frequently found to be cracked, but usually no ice protrudes from the rifts.

The growth of the ice fringe ceases when the ground is frozen to a depth of 2 to 3 cm., and when the moisture in the stem is frozen.

The size of the ice fringes and the height to which they extend above the ground depend upon the rate of evaporation from the stem, and upon the amount of moisture in the ground. Over 5 grams of ice may be formed upon a single plant during a single night.

Photographs are given of ice fringes formed upon stems which had been kept in the laboratory several months. They show that the ice may be formed upon stems without the roots. Hence the ice is not formed as a result of hydrostatic pressure exerted by the roots which are perennial.

All the observations are in agreement in showing that the moisture rises in the stem as the result of capillary attraction. The height (1 to 5 cm.) to which the moisture can rise within the stem is governed partly by the rate of evaporation from the surface. Photomicrographs of thin sections of plants are given, which show the structure of stems of plants which do not form ice fringes; also photomicrographs of sections of stems of plants which form ice fringes. It is shown that those plants which form ice fringes the most readily and in the greatest abundance have the most sap tubes.

The ice fringe is a composite of a number of very thin ribbons. In the laboratory the formation of the ice fringe was observed from its very beginning. The first stage in the production of the ice fringe consists of a single row of fine hair-like filaments of ice. This row of ice filaments lengthens up and down the stem. The filaments increase in number, thus forming a solid wedge-shaped tooth of ice, which constitutes the second stage of development. In the third stage of development the wedge-shaped tooth of ice widens and increases in length as the result of freezing of the water which continues to soak out of the stem. There appears to be no difference between the formation of these ice fringes and the columnar ice formed on wet soils; other than that, in the latter, a particle of gravel usually forms the nucleus to start the congelation. In both cases the moisture is brought to the surface by capillary action. When the rate of supply to the surface is more rapid than the loss of evaporation, and the air is at a sufficiently low temperature, ice is formed.